

ARTIFICIAL INTELLIGENCE AND SPACE POWER SYSTEMS AUTOMATION

David J. Weeks

NASA/MSFC

EB12

Marshall Space Flight Center, AL 35812

Abstract

This paper will discuss various applications of artificial intelligence to space electrical power systems. Completed, on-going, and planned knowledge-based system activities will be overviewed. These applications include NICBES (the expert system interfaced with the Hubble Space Telescope electrical power system test bed and one of the few NASA expert systems in daily operational use; the early work with SSES; the three expert systems under development in the Space Station advanced development effort in the core module power management and distribution system test bed; planned cooperation of expert systems in the CM/PMAD breadboard at MSFC with expert systems for Space Station at JSC and LeRC; and the intelligent data reduction expert system under development.

Background

The size and complexity of spacecraft power systems are increasing dramatically. America's first space station, Skylab, employed an eight kilowatt power bus. From fifteen to twenty ground support personnel were required to monitor and control the electrical power system on this early space station. At times, extensive crew involvement was necessary to correct system faults. [3] [4]

The Electrical Power Branch at Marshall Space Flight Center has been involved since 1984 with the development of expert or knowledge-based systems to facilitate the automation of electrical power systems. The expert systems developed thus far are focused on fault diagnosis and contingency payload scheduling. Systems now under development address comprehensive fault management, automatic rescheduling, and intelligent data reduction. Future plans involve the development of expert systems for battery management, trends analysis, and component failure forecasting. [5]

Several expert system prototypes have been developed including: the Hubble Space Telescope electrical power system test bed diagnoser /analyzer named NICBES (Nickel-Cadmium Battery Expert System), the Space Station Experiment Scheduler (SSES), and the Loads Priority List Management System (LPLMS). Other current and proposed automation activities will also be briefly discussed.

Hubble Space Telescope Expert System

The Nickel-Cadmium Battery Expert System (NICBES) is interfaced with the Hubble Space Telescope electrical power system test bed at the Marshall Space Flight Center. A functional block diagram is shown in Figure 1.

As presently configured, this breadboard is operated continuously and automatically telephones the test bed personnel at work at home in the event of a test bed anomaly. When these personnel arrive at the test bed site, they troubleshoot the system and take any steps necessary to restore the system to full operational status while protecting critical flight-type components in the test bed.

NICBES has three major functions in addition to the collection and storage of telemetry data from the test bed. The first function or mode is fault diagnosis. NICBES will independently verify the occurrence of an anomaly and recommend appropriate corrective actions. The second mode is status and advice. NICBES will evaluate the status of each battery in the test bed (there are six, 23-cell flight-type batteries) and give advice concerning each battery.

The third mode is the decision support graphics which offers 12 plots for any of the six batteries in the system. These plots display summary data for the 12 previous simulated orbits.

ORIGINAL PAGE IS
OF POOR QUALITY

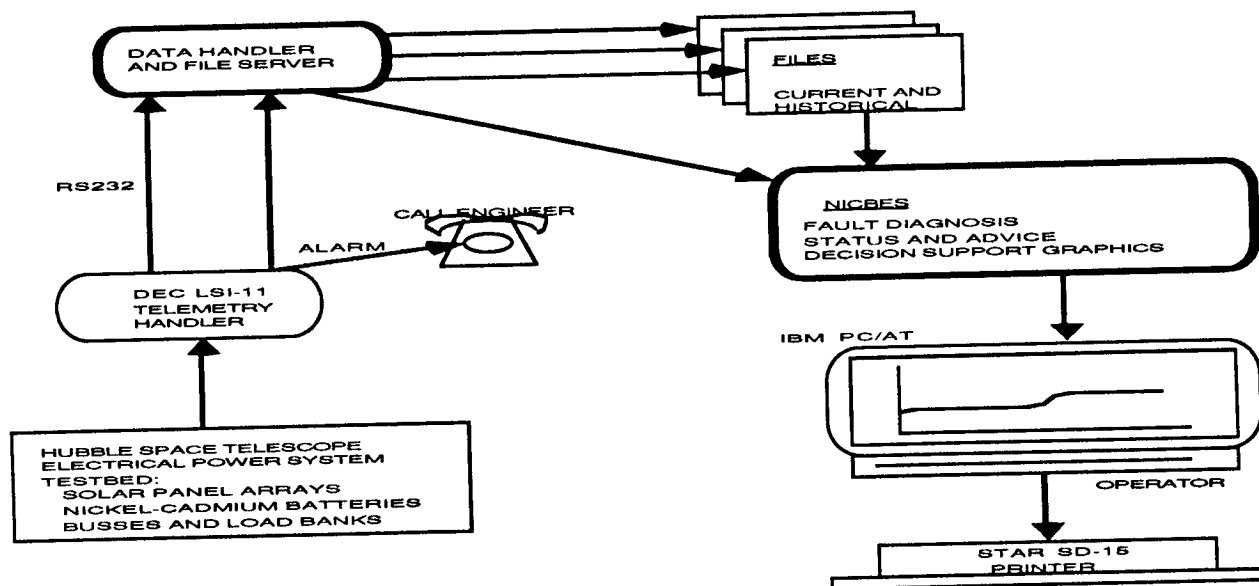


FIGURE 1. NICBES Functional Block Diagram

NICBES was developed by the Martin Marietta Denver Aerospace Corporation in Denver, Colorado under contract to NASA/Marshall Space Flight Center. [1] The expert system is implemented on an IBM PC/AT in Prolog.

Contingency Payload Scheduler

The Space Station Experiment Scheduler (SSES) is a proof-of-concept demonstration prototype expert system which schedules/reschedules payloads very quickly. Although SSES only employs about a few of the scheduling constraints that the Marshall Space Flight Center Experiment Planning System considers in Spacelab mission planning, it can reschedule 50 payloads for a full two week period in less than three minutes. It considers power consumption, payload duration, intermittent usage, crew attendance required, and priority class. Though a relatively simple model, this expert system demonstrates that a dynamic rescheduler embedded in a spacecraft power management system can help handle perturbations to the available power, assuring that power is utilized as it becomes available as well as avoiding the unnecessary load shedding of critical payloads in the event of a reduction of the available power. [2]

Space power has historically cost about \$1000 per kilowatt hour versus \$0.05 per terrestrial kilowatt hour. On Space Station maximum utilization of available power will be necessary to accommodate all the experiments and other payloads on board. In the event of reduction of available power, it is imperative that a critical load is never shed unless absolutely necessary. A Department of Defense or European Space Agency payload might be critical for national defense or due to international agreements; a science experiment may have a critical window for operation; or a materials processing payload may increase in importance as an expensive crystal nears completion and cannot be interrupted without incurring flaws.

The SSES was developed in 1985 by Technology Applications Inc. of Jacksonville, Florida as part of the Space Station Advanced Development program. It is implemented in Large Memory GC LISP on an IBM PC/AT with 3.5 megabytes. The graphics were coded in Turbo Pascal.

Space Station Core Module Power Management and Distribution System Automation Project

One of the most ambitious automation projects at the Marshall Space Flight Center is the Space Station Advanced Development effort for automating the Core Module Power Management and Distribution (CM/PMAD) system. The CM/PMAD breadboard will employ three expert systems in addition to extensive conventional automation software to control the power system breadboard as shown in Figure 2. The systems autonomy is pushed down as far as possible in the system such that in the event of an automation breakdown at the lower levels, the next higher levels will assume responsibility of the components below them in the hierarchy.

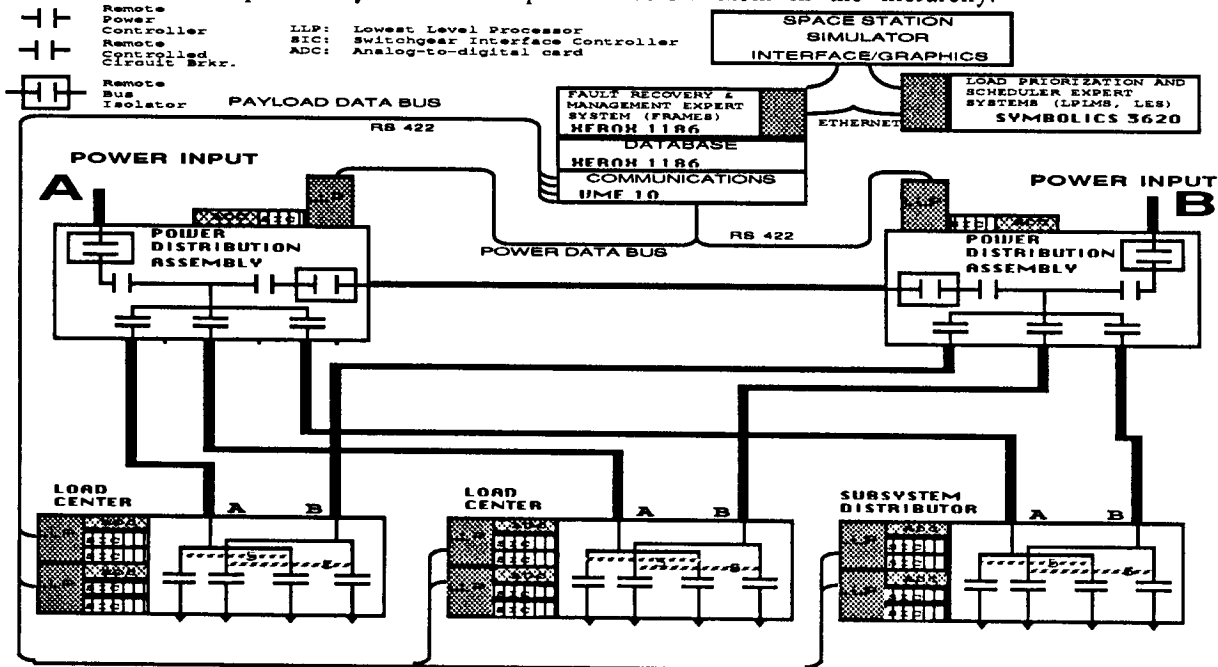


FIGURE 2. MSC SPACE STATION MODULE ELECTRICAL POWER SYSTEM BREADBOARD

The first of the expert systems is the Load Priority List Management System (LPLMS). The LPLMS maintains a real time dynamic representation of all the module loads and relevant facts so applicable rules can fire to reorder portions of the list as situations change.

The loads in a laboratory module may have dynamic priorities. A critical noninterruptible materials processing experiment involving crystal growth may have a different priority as its nears completion. Other factors may change priorities such as equipment malfunctions. An expert system such as LPLMS is critical in order to determine which loads must be shed in the event of perturbations to available power for the module. It is imperative that the 'critical' loads are not shed unnecessarily.

The LPLMS is currently implemented in the production language HAPS on the Symbolics 3600 series workstation. Load priority lists are sent down from the expert system to the conventional processors in the breadboard every 15 minutes.

LES, the Load Enable Scheduler, can schedule and reschedule a number of payloads with various scheduling constraints. This expert system will generate the baseline schedules for the breadboard as well as accept information from the other processors on when and how to reschedule the power system payloads. LES refines the ground load enable requests and builds a detailed mission activities list through simulation performance and list passing to the Supervisor Subsystem Simulator (SSS).

FRAMES is the Fault Recovery And Management Expert System. This expert system watches over the entire breadboard operation looking for anomalies and impending failures. FRAMES functionality actually extends to the lowest level processors in the breadboard for comprehensive fault management of the entire breadboard.

FRAMES is responsible for detecting faults, advising the operator of appropriate corrective actions, and in many cases, autonomous corrective action implementation through power system reconfiguration. The expert system will carry out trends analysis seeking incipient failures and soft shorts as well as open circuits.

The more conventional automation software resides in the power control unit (PCU) and in the lowest level processors (LLP). The PCU resides on a VME/10 system and performs process database updates on system data such as the load time enable, load time disable, primary remote power controller (RPC) number, secondary RPC number, switch permission number, nominal maximum power value, upper voltage limit value, lower voltage limit value, upper current limit value, lower current limit value, actual snapshot voltage value, actual snapshot current value, actual snapshot RPC total power value, and actual snapshot power value. The PCU also generates the process command list, allocates individual LLP command lists from the command lists generated by the Supervisor Subsystem Simulator (SSS) to the lowest level processors, allocates individual LLP priority lists generated from the overall priority list developed by the LPLMS to the LLPs, maintain the state of the actual load system within the present configuration list, graph the total power output as a function of time per bus, maintain a failed components list, maintain a major events list, provide a user interface for switching loads in and out (for emergency use where the user assumes full responsibility for the breadboard operation), function as the central communications device, allocate database change information to the SSS, and execute emergency shutdown procedures.

The lowest level processors maintain their individual command and priority lists, execute command control as directed by the individual command list, execute local load sheds as directed by their individual priority lists to save the bus from bad scheduling or overloading, execute data compression, execute data reporting, handle condition exceptions, execute automatic switch control, execute list directed switch control, verify configuration limits and allocations, and execute immediate commanded switch control. These processors are 68010 microprocessor-based controllers.

The SSS simulates various module interfaces such as to other subsystems, other elements of the overall Space Station electrical power system, the crew, and ground support elements. It resides on a Xerox artificial workstation though it is not itself an expert system.

Together these various elements comprise a fairly elaborate approach to power system automation. It is anticipated that this advanced development effort will contribute to the actual core module power management and distribution system automation on-board the Space Station. Martin Marietta is providing the contractor support for this system development. [6]

Marshall Space Flight Center is also cooperating with the Lewis Research Center in a 1990 Power Systems Autonomy Demonstration. This project involves the entire Space Station electrical power system test bed at two NASA Centers cooperating with the Space Station thermal control system test bed at NASA's Johnson Space Flight Center. Ames Research Center has overall responsibility for this project under the Systems Autonomy Demonstration Program.

Intelligent Data Reduction

The IDARE (Intelligent DATA REduction) project is a research effort involving the capture of the facts and heuristics that battery system specialists employ in determining the significant components of battery telemetry data. The research will be directed toward the Hubble Space Telescope power system test bed telemetry data and is expected to result in a knowledge-based system which autonomously reduces this telemetry data to its significant components for further trends analyses, improved system state-of-health monitoring, and fault prediction.

It is estimated that at any given time, perhaps 80 to 95 per cent of battery telemetry data is insignificant. It is hoped that the telemetry data can be reduced by an order of magnitude. As such data reduction is extremely labor intensive, an expert system would greatly reduce testing analysis and operational support.

The IDARE project is being conducted in cooperation with the University of Alabama in Huntsville under an university grant. If successful, applications are expected for complete elec-

trical power systems as well as other subsystems with propulsion personnel showing a special interest.

Conclusions

Knowledge-based or expert systems are being demonstrated for electrical power system applications involving proof-of-concept prototype intelligent systems. Artificial intelligence approaches should not replace conventional computer programs that work well. Instead, these knowledge-based systems should be employed to fill the gaps where traditional approaches either perform poorly or cannot be employed at all.

If autonomous electrical power systems are to be incorporated on future spacecraft, knowledge-based system prototypes must continue to be developed and demonstrated in fairly realistic electrical power system breadboards and test beds. Program managers must be convinced that these systems are safe, reliable, and can be developed within cost in a timely fashion.

References

1. Kirkwood, N. and D.J. Weeks, "Diagnosing Battery Behavior with an Expert System in PROLOG," Proceedings of the 21st IECEC, San Diego, CA, paper 869410, August 1986, pp. 1801-1807.
2. Touchton, R.A., "Common Module Dynamic Payload Scheduler Expert System," Proceedings of the 21st IECEC, San Diego, CA, paper 869406, August 1986, pp. 1785-1790.
3. Weeks, D.J. "Application of Expert Systems in the Common Module Electrical Power System," SPIE Vol. 580 Space Station Automation, Cambridge, MA, September 1985, pp. 35-39.
4. Weeks, D.J. and R. T. Bechtel, "Autonomously Managed High Power Systems," Proceedings of the 20th IECEC, Miami FL, paper 859157, August 1985, pp. 1.132-1.138.
5. Weeks, D.J. "Expert Systems in Space," IEEE Potentials, Vol. 6, No. 2, 1987, pp. 18-21.
6. Weeks, D.J. "Space Power System Automation Approaches at the George C. Marshall Space Flight Center," Proceedings of the 22nd IECEC, Philadelphia, PA, paper 879104, August 1987, pp. 538-543.